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CURRENT PERSPECTIVES IN HYPERBARIC PHYSIOLOGY, ULTRASONIC
DOPPLER BUBBLE DETECTION, AND MASS SPECTROMETRY

DR. B.G. D'AOUST*

28 DECEMBER 1979

*Virginia Mason Research Center
Seattle, WA

UNITED STATES OF AMERICA

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<p>Two important analytical techniques in biomedical research have been increasingly utilized in hyperbaric physiology over the past 12 years. Doppler ultrasonic bubble detection on the one hand and mass spectrometry on the other have been used to demonstrate responses to both elevated pressure and decompression which have previously been only conjecture. Both techniques have raised controversies, yet both, properly used, are capable not only of resolving them but also resolving many of the questions which have remained unanswered. The article discusses the "state-of-the-art" of these two tech-</p>		

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niques in hyperbaric medicine and some of the more promising areas for the future.

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CURRENT PERSPECTIVES IN HYPERBARIC PHYSIOLOGY,
ULTRASONIC DOPPLER BUBBLE DETECTION, AND MASS SPECTROMETRY

It has been known since the time of Robert Boyle (1627-91) and somewhat more recently through the classical studies of Paul Bert, (1833-86) the famous French physiologist ("La Pression Barometrique") that decompression sickness and Caisson Disease are caused primarily by the formation of bubbles of gas in tissues and blood.

Fundamental research in this area in both France and the US as well as other countries in Europe, in particular Britain where the Haldanes made their lasting contribution to the field, has continued for many years since then, always with some new insight but always slower than one would like. This correspondent has been involved in this field for approximately 12 years—just about the same amount of time which marks the inception of two new, potentially very powerful techniques into biomedical research in general and into hyperbaric physiology in particular.

These two techniques based on quite different principles in technology have nonetheless been recently focused vigorously on diving medicine, one with considerably more success than the other. Both, however, offer the availability of information on decompression sickness previously quite out of the question and, therefore, both are under investigation to various degrees in all countries.

The first type of technology involves the actual acoustic visualization of bubbles in divers by means of sending high frequency sound into the desired blood vessel—usually the pulmonary artery—and analyzing the "Doppler shifted" returning signal electrically. This principle was first used around 1960 to detect blood flow in vertebrate physiology studies. The "Doppler" shifted signal is exactly the same phenomenon as used in radar and other forms of spectral analysis providing information on velocity of wave reflecting entities. In this case, however, it is the formed elements of the blood that chiefly reflect the sound, the frequency of which is approximately 2 to 10 MHz, depending upon the application. When, however, a bubble enters the sonic field, a very high amplitude return is heard with a unique frequency envelope. It appears that several investigators hit on this idea at the same time; however, a story circulates that in the late 60s Dr. Dennis Walder (Newcastle-upon-Tyne) and Dr. Merrill Spencer were discussing the problem of ultrasonic detection of blood flow measurement in experimental animals and the difficulties encountered in dealing with bubbles that often were introduced by blood oxygenators used in connection with the anesthetized operational preparation. Walder, long an expert on diving medicine, is reported to have asked if it might be possible to hear the bubbles in divers this way, and it would be tactless of this writer to venture an opinion as to above whose head the light bulb flashed first. Nevertheless, both Spencer and Walder, and later others, proceeded independently to demonstrate the feasibility of this technique. Another group at Battelle Northwest Lab-

oratories in Richland, Washington, USA (M. Griffiths) also showed the feasibility of the technique (later at the same laboratories, bubbles were also demonstrated in salmon unavoidably subjected to swimming in supersaturated waters—a common hatchery and a recent ecological problem in the Northwest caused by multiple dams on the Columbia River).

In any case, it was soon used in half dozen laboratories in both the United States and Britain, both military and civilian as well as private (Virginia Mason Research Center and Institute of Applied Physiology in Medicine). And much more recently, it has been used in France in the course of studies of saturation diving excursions by Gerald Mazurel ((CERTSM Division of Toulon Naval Base). Ten years have passed since these first demonstrations of feasibility; about this time there was also a very great extension in depth and type of diving; saturation diving had come of age. It is perhaps, surprising therefore, that we still know so little. The reasons, of course, are to be found partly in the usual combinations and constraints of scientific research of our age and also partly in the unique difficulties inherent in carrying out this particular type of research. To appreciate these limitations, it is necessary to consider in a little more detail some of the basics of hyperbaric physiology.

Breathing air or in deep diving, helium/oxygen, or as is used in some cases helium/nitrogen/oxygen or tri-mix, allows solution of gases in all of the tissues of the body in a greater concentration than at surface pressure which is termed one bar or one atmosphere (atm). After a certain maximum time, the body will have become saturated with gas such that no further amount will dissolve. This is, thus, the basis of the economic advantage of saturation diving, almost a household word now for the past ten years and always associated with the off-shore activity in exploration for oil. The point of the above relative to this report is that the decompression required following such activities is extremely slow, initially 1.3 m/hr and as the surface is approached, often as low as 1.0 m/hr. In this situation very few bubbles are ever recorded in operational dives. This observation has allowed the notion that the detection of bubbles in saturation diving is of rather little use in predicting the outcome of the decompression. Exceptions appear to be deep experimental dives such as those that have been carried out at the Duke University chamber and the University of Pennsylvania's Institute of Environmental Medicine, Philadelphia, and some studies performed in San Diego by Sub Dev Group 1. Even in these, bubbles were rare.

By contrast, in the Doppler investigation of short non-sat dives initially at VMRC by Spencer and later by Kent Smith, it was common to encounter bubbles after surface dives with short or limited decompression diving and while these facts had great impact on the theories at that time, little light was shed on how they should be changed to avoid undue risk or to avoid unnecessary time (obviously it is quite possible to decompress safely but it is human nature in most Western countries that

we spend much of our resources on trying to have our cake and eat it too). Safe decompression is quite simple if one comes up slowly and takes more time than is thought necessary. However, although effective, this technique sheds no light at all on the actual etiology and mechanism of decompression sickness which, after all, is what we need to know.

Thus, the ultrasonic Doppler bubble detector provided firm qualitative proof that decompression procedures considered safe were capable of causing bubbles that could be detected at the heart. The obvious next questions were ones of degree: What is the relationship of the bubble to decompression sickness? Can the bubbles serve as an early warning? and so on. That we do not yet have the answers can be attributed as much to the unique difficulties surrounding the use of the technique as to the relatively small numbers of investigations underway. At first sight, it might seem surprising that information which is potentially available with a non-invasive technique is so hard to come by. The explanation to this, in part, is the training and teamwork necessary on the part of the physician, researcher and/or technician before signals can be reliably received, recorded, and interpreted.

The actual Doppler sound made by a bubble passing through the insonified volume blood vessel resembles a very sharp truncated whistle, chirp or click depending upon the frequency used and given the frequency, a number of other factors which are chiefly: a) the size of the bubble, b) its velocity, and c) its position in the sound field.

It takes considerable familiarization (probably even for a rock musician) to distinguish these sounds from those of similar frequency produced by heart valves, vessel valves, and wall motion, etc. Fortunately, when a good signal-to-noise ratio exists, bubbles passing through the pulmonary artery (PA) where most of the Doppler probes are focused in man, have a high amplitude and are more acoustically "visible" because the acoustic impedance of a gas phase as compared to that of blood and all of its components is at least an order of magnitude or two higher. Nevertheless, training is necessary and results subjective at best. The stimulus, therefore, for automatic counting has resulted logically from the nature of the Doppler signal.

Spencer currently at the Institute of Applied Physiology in Medicine, Seattle, WA, was one of the first to provide a systematic "bubble grading system." He held a workshop for just this purpose just before the Undersea Medical Society Meeting in Seattle in April 1978 and several bubble counting and grading procedures were discussed at that workshop. K. Kisman and Mazurel (CERTSM, Toulon) introduced a modification of the Spencer system at that time ranging from the strictly clinical, as first introduced by Merrill Spencer, to the highly technical as first introduced by Dean Haugan and Dr. Ed Belcher (Applied Physics Lab, Univ. of Washington, Seattle)

in 1974. The writer in collaboration with Belcher continues to use the more automatic method chiefly caused by the nature of the experiments ongoing at VMRC (usually on experimental animals equipped with Doppler cuffs around the major veins). The Spencer grading system, however, is also used in various studies involving human divers.

It is important to realize that all automatic counting methods are currently at the mercy of signal quality and vary between individuals from time to time. At the workshop mentioned above, Dr. Nashimoto actually demonstrated this objectivity by showing results of bubble grading by five or six separate individuals who analyzed the same recordings. While there were considerable differences in their subjective impressions, there was, nevertheless, also consistency in that all individuals agreed on whether one recording showed more bubbles than the other.

At the same workshop, Mazurel introduced results of some of the first saturation excursion decompressions using a slightly different bubble grading system. His group has been extremely active and aggressive in their use of the Doppler and there is now a French model available made by the "Sodelec" Company in France. Such studies are much more difficult under saturation conditions, as mentioned above, and few have been carried out. It is therefore of interest that some of Mazurel and Kisman's recent results contradict the notion that Doppler monitoring is not useful for evaluating deep saturation dives; to some extent they suggest that Type II bends involving the central nervous system and particularly vestibular problems may be significantly related to Doppler bubbles detected over the precordial region; for pain-only bends, this does not appear to be so.

One of Mazurel's interesting conclusions reported earlier was that the mean bubble count or "grade" during the final decompression appeared to be related to the severity of the excursion dives occurring before the final decompression. This recalls the previously suspected danger of the depth and time of a prior excursion and it must always be considered as a cumulative stress when followed by a saturation decompression.

It is known that the numbers, temporal patterns, and time of first appearance of bubbles vary considerably from subject to subject. Some objective criteria of the quantity of bubbles is, however, necessary and the grading systems introduced by Spencer and used by almost all laboratories involved in this work to some degree is, if nonlinear, at least fairly consistent. This we can be sure of after approximately five years of comparing notes with various workers. Thus, the Doppler bubble signal is "graded" on the basis of the numbers of bubble sounds between each heart cycle—since the latter is the bulk of most of the sound one hears—according to the following convention:

- Grade 0 No bubble sounds.
- Grade 1 An occasional bubble discernible within the cardiac motion and with the majority of the cardiac periods free of bubble signals.
- Grade 2 Is designated when many, but less than half of the cardiac cycles contain bubble signals.
- Grade 3 When most of the cardiac periods contain bubble signals but not overriding the cardiac motion signals.
- Grade 4 Is the maximum detectable bubble signal heard continuously throughout systole and diastole of every cardiac period, and overriding the amplitude of the cardiac motion signals.

This scheme is consistent but obviously nonlinear, and, as can easily be imagined, falls down at levels above Grade 3 (which all investigators now agree becomes quasi-clinical in the sense that it is often associated with bends pain or CNS bends symptoms), it is difficult, and in some cases impossible, to assess the number of bubbles. This has stimulated the various electronic approaches, one of which was mentioned above by Hagan and Belcher and a second ongoing method has been approached by Kisman at DCIEM, Canada in collaboration with Mazurel at CERTSM. The latter pairs of workers have also constructed a more comprehensive coding scheme in an attempt to extract more information aurally from the signal. Accordingly, whereas the Spencer grading system scheme uses only the bubbles per heart cycle, the Kisman/Mazurel scheme or KM code as it is referred to, attempts to enumerate also the bubble effects at rest (C) (R) and with movement (C) (M); a bubble grade the same as Spencer's is then established for each case as described above. However, in the KM code, several other parameters are introduced. One is called the "percentage" which simply means the percentage of cardiac cycles in a certain time having a certain grade of bubbles. A second new parameter is described as the amplitude or strength of the bubble signals. A third parameter is the "duration" and applies only when the diver performs a movement and is expressed as the number of successive cardiac cycles following the movement having a specified bubble frequency and amplitude. It will be apparent that this approach will extract more information from the sound but also can construct a formidable array of data and require considerable human time and energy in construction of the matrix and its evaluation. However, one merit is that it is amenable to computer analysis and may

provide more information available by subjective listeners than previously available by this technique. On the other hand, successive replaying of the portion of the recordings will also be necessary to arrive at these codes, involving extra time and data analysis. It thus remains chiefly a research approach.

Both Kisman and Mazurel have tested their approaches on operational research saturation dives in the open sea (Janus IV) and this remains to date one of the very few such studies using Doppler effectively as a decompression monitor during the procedure. Here too the authors concluded that correlation was low and variable for saturation decompression but nevertheless suggested decreasing the decompression rate to minimize bubbles. Thus, it does appear that in saturation decompression which is limited by the tissues exchanging gas the most slowly, Doppler bubble detection is of use when deeper excursions have been made. On the other hand, as an excursion monitoring technique, like surface supplied diving, it remains of high interest. Here again, Mazurel has been an extremely busy investigator and has produced some very useful insights. He has personally observed, using Doppler, one diver who had sustained a right shoulder injury the week before his dive. The diver showed, upon decompression, many bubbles passing through the right subclavian vein and none on the left which was his "good" side just as might be expected by the impairment to perfusion that injuries can produce. It is this sort of account which continues to suggest that the Doppler ultrasonic bubble detection approach remains both a useful research as well as a clinical tool and provides some clinical promise, provided sufficient familiarity is obtained.

It is this latter constraint, *viz* the training and experience required (which is due to the subjectivity of the information obtained), which is partly responsible for current controversy regarding the utility of Doppler bubble detection for evaluating divers, patients, and decompression tables.

The question as to its degree of correlation between acoustically detected precordial bubbles and decompression sickness has not yet been satisfactorily answered. Having suffered from decompression sickness on three separate occasions that were always preceded by bubbles detected ultrasonically, this correspondent would willingly be the first to insist that there is one, but again without qualification, admitting readily that differences exist between Type I and II bends and between saturation diving and surface oxygen decompression cloud, the interpretation of the visibility of precordial bubbles by Doppler. Thus, the lack of good correspondence between bubbles detected by Doppler and incidence of decompression sickness depends very much on the kind of decompression protocol or "profile" investigated, that is, the precise time depth curve and staging

used in the decompression. It has long been known that a short deep dive may produce a few bubbles whereas a longer, more shallow dive may produce many more bubbles (here again, the difficulty in testing all combinations on each individual in a reasonable time severely limits this research). Thus, there has to be a certain critical amount of gas in the individual as well as certain critical pressure drop to cause bubbles to be formed, collected by the (already compromised) circulation and acoustically detected at the central venous location. Just what these levels are remains an area vigorously investigated, but for which the prospects must be considered limited. Add to this the fact that it is now known that gases are not eliminated from the body as rapidly following decompression as they are normally (Kindwall, 1974; D'Aoust, et al., 1976) and there becomes much room for different interpretations of the merits of Doppler bubble detection as a decompression tool even for research.

Given the above, the desire to have automatic electronic bubble "grading" or counting techniques in experimental research is quite understandable. There are two ongoing approaches at the present time in attempting to actually count bubbles passing the sensor. One of these by Belcher is now in at VMRC in studies of both decompression-induced and bubbles and counter-diffusion-induced bubbles. The Doppler signal received is extremely complicated and carries many discrete wave spectra. Thus spectral analysis comes to mind.

On theoretical grounds this is the technique of greatest potential analytical power, requiring successive power spectral analysis of the signal and, as initially carried out by Kisman and Mazurel, requiring playback of recorded signals in 1/32 to 1/64 real time. In this situation, the power spectra, that is the energy vs frequency distribution of the Doppler signal received, is examined by using spectral wave form techniques and when bubbles are present the striking differences can be demonstrated between normal heart and blood flow sounds and those in which bubble signals are "hiding." This requires the presence of rather expensive and sophisticated computing equipment and programming, but it is hoped by Kisman, Mazurel, and colleagues, as well as others, that when required spectral signal analysis and computer programming is better defined, a smaller, more efficient "black box" may be designed to accomplish the task automatically. While feasible, this is a few years off at least, and is still nevertheless a disadvantage for real time continuous studies when for one reason or another it is desired to record continually the entire period after or during a decompression. This preference originated the first approach in 1974 used by Haugan, Belcher, and K. Smith.

This approach uses an array of what are called Butterworth filters as a "comb filter" for which there is considerable precedent in acoustic and other wave analysis. As in the KM technique, the received Doppler shifted flow and bubble signals which are "hiding" in the 5 MHz Doppler

carrier are FM demodulated by a mixer removing the higher frequency carrier and leaving the audible Doppler flow signal of varying amplitude, frequency and signal-to-noise ratio. This signal is then with some automatic gain control passed into the comb filter/counter. There are 12 channels or band widths in the model first developed by Belcher and Haugen and used at VMRC, and 16 channels in a newer version completed by Belcher in the past year. There are two criteria of the signal which must be electronically controlled in counting the bubbles in this manner. One is the frequency, i.e., each filter will pass some frequency and reject others, and the other is the amplitude. This is where the going gets a little tougher because in many situations, the SN ratio is constantly changing and the discrete acoustic return of a bubble depends upon a) its velocity, b) its position in the insonified field, and c) its size. Because of these variables, the circuitry is arranged so that the signal passing each filter must have a certain minimal amplitude to be counted. It may be correctly surmised that there are difficulties here too when one considers the sound of heart motion, heart valves that strongly resemble bubble sounds, and so on. The response to this problem by Belcher is an adaptive computer algorithm that "keeps track" of the average signal level passing each filter and by taking the mean of five or six of these channels in which much of the background signal is quite similar, the system is able to cancel out unwanted signals and thereby both increase the probability of correct count and decrease the probability of incorrect counts.

In all of these techniques, if carried out on man in order to get the required signal quality, excellent cooperation on the part of both diver subjects and analysts is required to produce good results. Kisman and Mazurel at DCIEM are investigating these at the same time since each have unique merits that the other lacks. The one outstanding consideration of the Haugen/Belcher approach is, of course, the ability of real time continuous analysis, and the outstanding advantage of the spectral analysis approach may be the much greater potential analytical power which can be trained on the Doppler signal. It may not be unrealistic to hope that with this technique subtle differences may be detected relating to the specific entities returning the acoustic echo; fat droplets, small thrombi, bubble size, and so on.

This discussion would be quite incomplete if it did not mention a third and very promising approach in which investigation and hopefully development has been initiated by S. Sjøvik, Chief of Instrumentation at the recently completed Norwegian Underwater Institute in Bergen, Norway. This organization which is a facility jointly funded by Norsk Veritas and the NTNF of the Norwegian government has developed a vigorous program in research in marine engineering and technology including diving

and associated instrumentation. The approach under investigation by S. Sjøvik, Belcher, B.G. D'Aoust and H. Seibold of Virginia Mason Research Center in Seattle, will attempt to use a partially holographic technique using two crystals transmitting an array of independently selectable crystals as receivers to try to remove much of the motion-induced noise discussed above. If feasible, the outstanding advantage of this approach would be that it would leave the diver/subject free to go about his other tasks without the high degree of teamwork necessary to achieve this result under operational experimental conditions. Apropos the latter, it is appropriate here to pay some tribute to the French programs in their tenacity for successful acoustic monitoring, specifically the work in the Janus IV excursion dives. Having been both a subject and an investigator under much less trying circumstances, I can personally attest to the degree of teamwork and cooperation required at all levels to accomplish this kind of experiment, particularly when it is known that the results are rarely completely clear, often confusing and never amenable to standard statistical analysis. Yet, these results are all we have at present, and, in spite of their limitations, they have provided a significant contribution to the current understanding of decompression sickness as well as an objective non-invasive technique.

Thus, although promising to provide some further insights as to the details of bubble formation and clearance in the body during diving, the ultrasonic Doppler technique has strong limitations that suggest pursuit of alternative techniques in understanding gas uptake elimination and bubble formation, as well as the physiological sequelae that these effects have on the diver.

This situation logically introduces the next area of technology discussed herein which has attracted several investigators in hyperbaric physiology. Biomedical mass spectrometry has, in a manner analogous to the Doppler ultrasound, suffered the "slings and arrows of outrageous criticism" to borrow and beat a phrase. It is not appropriate to go into this here save to mention that most of the criticism center on the use of tissue probes. A group at The Centre D'Etudes et de Recherches Biophysiques, (CERB) the third large naval medical establishment in Toulon, France, has been working on and with this technique for some time. This group is directed by B. Broussolle, and includes R. Hycinthe and P. Giry, all of whom are extremely versatile investigators. In a recent visit there the writer, also occupied with Doppler bubble detection and gas uptake and elimination, spent a very productive day with these investigators. Unfortunately, the biologist with CERTSM branch of Toulon Naval, Gerard Mazurel who has aggressively used the Doppler bubble detector in saturation excursions as described above, was absent on vacation during my visit.

However, one of the fringe benefits of research is the occasional meeting of likemindedness in parallel but independently originated lines of thought in colleagues one has never met or perhaps even heard of. This was so with my visit to Broussolle, Hyacinthe, and Giry at Toulon Naval. It is one of the most active groups in French hyperbaric research, and it is extremely innovative as well. The signs of this innovation and versatility are everywhere in the laboratory and include such areas as blood rheology, immunology, hematology, pulmonary physiology, fitness studies (Hyacinthe), and fundamental experiments on the use of mass spectrometry *in vivo*.

Giry has developed his own mass spectrometer blood probe rather than accept those previously on the market, use of which has received severe criticism over the past ten years. They have calibrated their probe and its time constants for several gases at 100 bar, and it appears to be superior to those commercially available. Its construction is simple and available with current state-of-the-art methodology and materials. The critical aspects of this development have been reported in this year's Undersea Medical Society Meeting in Key Biscayne, Florida last June [Supplement to UBR 6(1), March, 1979]. Unlike the probes commercially available in the United States, this style uses a thinner membrane produced by dipping in silastic suspension which coats a sintered nickel metal frit of very small porosity (1 μ) which fits inside a stainless steel tube. The porosity is approximately one micron and could be varied if required. However, the sintered nickel frit is available from a company in Paris, Metafram, Inc., and it is swaged to the inside of the end of the tube and the probe is successively dipped in liquid silastic Dow-Corning Q-7 or MDX-44515 silicon dispersion to form the membrane.

The probe has response times ranging from 7 sec. (for helium) to 154 sec. for SF₆. These time constants can be very reproducibly calibrated for each probe and should permit calculation of total gas pressures being observed by the probe.

The way these investigators have been using the probe struck sympathetic cords with me since at VMRC we have developed a similar mass spectrometry system and will use similar techniques for measuring mixed venous blood gas concentration in awake goats.

For several years in the US, mass spectrometry has been used in respiratory physiology with much success, however, tissue probes have met with difficulties many of which were rather uncritically neglected by the early investigators.

However, the ability to place a fine needle-like probe into the tissue or blood vessel of interest and learn the gas tensions therein is obviously

very attractive to biomedical researchers, and it is to be hoped that attempts will continue to overcome these experimental difficulties, particularly for hyperbaric medicine where neither the exact state of gas saturation nor the average "critical" supersaturations are known.

Giry has developed the necessary calibration system for his probe which can be run on line with the experiment. He has been able to demonstrate, apparently directly with the probes, a counterdiffusion-produced supersaturation in arterial blood following gas switching. While theoretically surprising, this phenomenon might be explained by a degree of pulmonary shunt attending the anesthetized preparation. In fact if this is so, it would be likely that the degree of supersaturation produced by such a gas switch would be indicative of the degree of shunting! The phenomenon of counterdiffusion supersaturation was first described as a potential hazard in man by Lambertson's group in Philadelphia in 1972. This is distinctly different, of course, from the transient counterdiffusion under saturation used by Hans Keller in 1962 to attempt to provide a decompression advantage during a deep bounce dive.

The group at CERB are in collaboration with Dr. Peter Tikuisius (DCIEM, Canada) who has formulated one of the several mathematical models available these days which purport to describe more exactly what the experimentors are usually the first to observe. Obviously both approaches are necessary; however, the particular merit of experiments carried out by Giry is that he has demonstrated that a short pulse of supersaturation (which might be considered theoretically impossible) in the arterial blood immediately upon gas switching from nitrogen to helium can indeed occur. The physiological implications of this are not yet clear but at least we now know that it may explain some of the immediate effects of gas switching. Giry has shared some of his data with me and demonstrated his ability to calibrate the apparatus under the pressure using solenoid valves and tonometers.

The response times of Giry's probes are quite remarkably good—different of course for all gases, which has been another point somewhat under-emphasized by the commercial manufacturers. The technique of fabrication is simple, and it is probable that other investigators will also begin constructing their own probes over which they will have much more control. The critical technology here is the sintered metal frit, available from the French company, Matafram, 56 Rue de Dondres, Paris 75008, and the silicon rubber suspension from Dow-Corning specialists in the United States. The most essential ingredient of all of this is recognition that constant calibration is required and the experimental setup at CERB indicates great attention to this problem.

In summary, the Division of CERB under the direction of Broussolle is impressive in the number of interdisciplinary studies going on and the vitality and experimental versatility which is always associated with

such arrangements. This is something often lacking, unfortunately, in laboratories in the United States where for too long we have allowed ourselves the misconceived luxury of the "specialist" concepts in our approach to basic research. As budgets are on the wane for this sort of approach, one of the good results may be a return to emphasizing and selecting for such versatility, which will be undoubtedly good for science but perhaps not necessarily good for all scientists!

Also under construction in Toulon and part of CERTSM is a very large, high-pressure complex for hyperbaric research. It consists of two triple-lock complexes, one to be rated to 500-m and the other to 1000-m, and a third single-lock 1500-m high-pressure chamber of 1.5-m diam. for work on large mammals. The largest lock will be 30 m³ (approximately 1060 ft³). Large compressor capacities and means of storage as well as good atmospheric and water temperature control will be included. Like so many one-of-a-kind projects, progress is behind schedule but proceeding steadily and when completed should provide complete experimental and operational testing capability for manned diving.